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Economic Evaluation of an Electrolytic Process To Recover Lead From Scrap Batteries

By Thomas A. Phillips

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A/m^2	ampere per square meter	kW·h/lb	kilowatt hour per pound
°C	degree Celsius	lb	pound
cm	centimeter	lb/d	pound per day
d/wk	day per week	lb/h	pound per hour
d/yr	day per year	m	meter
ft	foot	Mgal	thousand gallon
ft^2	square foot	min	minute
ft^3	cubic foot	MMBtu	million British thermal unit
gal	gallon	pct	percent
g/L	gram per liter	st	short ton
h	hour	st/d	short ton per day
h/d	hour per day	thm	therm
kW	kilowatt	V	volt
kW·h	kilowatt hour	yr	year
kW·h/kg	kilowatt hour per kilogram		

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ECONOMIC EVALUATION OF AN ELECTROLYTIC PROCESS TO RECOVER LEAD FROM SCRAP BATTERIES

By Thomas A. Phillips [1]

ABSTRACT

This publication is an economic evaluation of the Bureau of Mines electrolytic process for recovering lead from scrap lead-acid batteries. In this process, scrap batteries are crushed and separated into metal and sludge fractions. The metal fraction is cast as anodes and electrorefined. Lead in the sludge fraction is converted to lead carbonate by reaction with an ammonium carbonate-ammonium bisulfite solution. The lead carbonate is then dissolved in a fluosilicic acid electrolyte from which pure lead metal is electrowon.

A cost estimate is presented for a plant capable of processing 10,000 scrap batteries per day. The fixed capital cost for this plant is estimated to be $14 million on a fourth quarter 1984 basis. Operating costs are estimated to be $0.15/lb Pb recovered. Assuming a lead selling price of $0.17/lb, the interest rate of return on investment after taxes is 11 pct. A lead selling price of about $0.21/lb is needed to obtain a 20-pct-interest rate of return.

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INTRODUCTION

The recovery of secondary lead from scrap lead-acid batteries currently requires that the batteries be smelted in a furnace. Typically, reverberatory and/or blast furnaces are used. These invariably release some sulfur dioxide and lead fumes to the atmosphere; owing to tightening emission and workplace exposure standards, these emissions are difficult to adequately control.

Researchers at the Bureau of Mines Rolla Research Center have developed alternate technology to recover lead from battery scrap. The metallic portion of the scrap is melted and cast as anodes that are electrorefined. Lead in the battery sludge is leached and electrowon by a novel technique patented by the Bureau of Mines (1).[2]

The technical feasibility of this approach has been demonstrated and reported in RI 8602 (2) and RI 8857 (3). This report contains an economic evaluation of the Bureau's process to aid in assessing its potential. Capital and operating costs are included for a commercial-scale plant based on a conceptual flowsheet developed from the Bureau's research.

PROCESS AND PLANT DESCRIPTION

In the proposed process, scrap batteries are crushed and separated into four products: Waste sulfuric acid, plastic and rubber casing material, metallic lead, and a fine sludge. The waste acid is neutralized with lime and discarded. The plastic casing material may have some market potential, and the rubber is a waste product.

The metallic portion of the scrap is melted and cast as anodes, which are electrorefined using a fluosilicic acid electrolyte. Lead in the sludge, as either a dioxide or sulfate, is insoluble in fluosilicic acid, so it is converted to lead carbonate by treatment with a solution of ammonium carbonate and ammonium bisulfite. The lead carbonate is then leached with fluosilicic acid to produce a solution from which lead is electrowon. The major operations are shown in figure 1.

Based on this process, a plant has been designed to recover about 82 st/d Pb from 10,000 scrap batteries. This scale is approximately the scale of a large secondary smelter. For description, the plant has arbitrarily been divided into five sections: Feed preparation, anode casting, leaching, electrolysis, and ammonia recovery. The sizes of the major items of equipment for each section are shown in table A-3. Daily thermal and utility requirements for each section are also shown in appendix A. The plant is designed to operate 7 d/wk with the feed preparation and anode casting sections operating one shift and the remainder of the plant operating three shifts.

FEED PREPARATION SECTION

Scrap batteries are assumed to be delivered to the plant by truck and dumped on an acid-proof pad. The batteries are picked up by a front-end loader and fed to a crushing and classification system. This system is available as a packaged unit and is capable of classifying battery scrap into the proper components.

In the system, whole batteries are fed to a stainless steel hammer mill and crushed to a "workable" size. Discharge from the hammer mill flows through a series of classifiers, which separate the scrap into distinct fractions, including a metal fraction consisting of grid metal and battery posts and a sludge fraction of lead sulfate, lead oxide, lead dioxide, and fine metallic lead particles. The plastic casing components and hard rubber components are also recovered as two separate fractions.

Waste acid from the batteries and water used in the classification system are collected and mixed with lime to neutralize the acid. An average acid strength of 14 pct H_2SO_4 is assumed for material

[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

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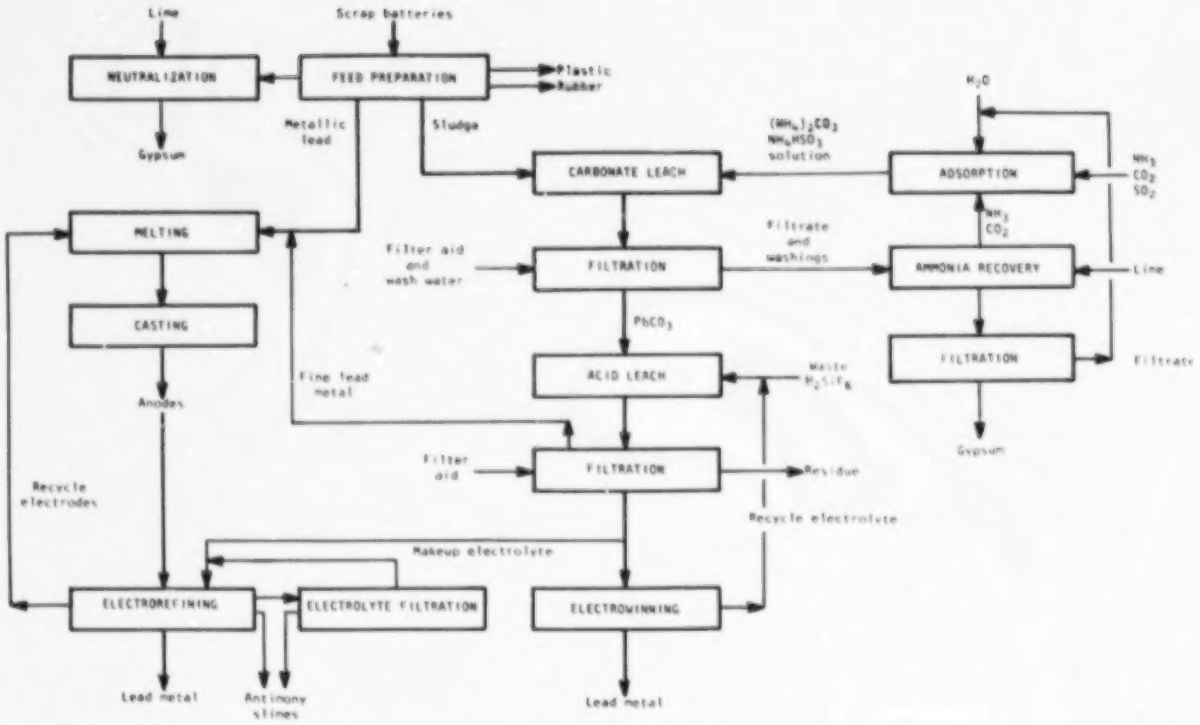

FIGURE 1. - Electrolytic process for recovering lead from battery scrap.

balance calculations, although it may vary from 4 to 20 pct. The neutralized slurry flows to a pond, where the solids settle. Periodically the pond is dredged to remove the solids for disposal. Overflow from the pond is pumped through a sand filter for reuse in the process or discharge to a sewer.

ANODE CASTING SECTION

Metal from the feed preparation section is fed to a melting furnace along with recycled anodes from electrorefining and fine lead prills recycled from the leaching section. Upon melting, a slag forms from the oxidized portion of the feed, protecting the molten lead from further oxidation. (A portion of the slag is periodically skimmed from the furnace, allowed to cool, and discarded.) Molten lead from the casting furnace is poured into molds, forming the anodes. Each anode is approximately 0.75 m by 1.5 m by 1 cm. These are arbitrary dimensions.

LEACHING SECTION

Sludge from the feed preparation section is mixed with an ammonium carbonate-ammonium bisulfite solution and heated to 55° C. Average retention in the carbonate leach is 1 h. During this time, the following reactions are assumed to take place:

$$PbSO_4 + (NH_4)_2CO_3 \rightarrow PbCO_3 + (NH_4)_2SO_4$$

and

$$PbO_2 + NH_4HSO_3 + (NH_4)_2CO_3 \rightarrow PbCO_3 + (NH_4)_2SO_4 + NH_4OH.$$

The lead carbonate formed is insoluble and is recovered and washed on a rotary-vacuum drum filter. A filter aid is required to give adequate filtration rates. Both filtrate and washings are pumped to the ammonia recovery section.

To dissolve the lead carbonate, the filter cake is mixed with recycled fluosilicic acid electrolyte from the

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electrolysis section. The electrolyte initially contains about 120 g/L free H_2SiF_6 and about 50 to 70 g/L Pb as $PbSiF_6$. Leaching at 45° C for 30 min increases the lead content of the electrolyte to about 100 g/L. The primary leach reaction is assumed to be

$$PbCO_3 + H_2SiF_6 \rightarrow PbSiF_6 + H_2O + CO_2.$$

Unreacted solids, primarily metallic lead, lead sulfate, and some phosphate compounds, are mixed with additional filter aid and separated from the loaded electrolyte in a rotary-vacuum drum filter. The filter cake is discharged to a screen, and much of the metallic lead is separated for recycle to the anode casting section. Solids passing the screen are allowed to dewater and then collected for disposal. These solids are stable and can be discarded in a landfill. Loaded electrolyte from the filter is pumped to the electrolysis section.

ELECTROLYSIS SECTION

Electrorefining

Anodes from the anode casting section are placed in electrorefining cells. It is assumed that 30 anodes will be refined per cell. Cathodes are 0.16-cm-thick lead starter sheets. Spacing between electrodes is 3 cm. The electrolyte is fluosilicic acid, which flows by gravity from a head tank through the electrorefining cells to a sump. From the sump the electrolyte is pumped up through a clarifying filter to the head tank. Makeup electrolyte is taken from the electrowinning circuit.

Anodes are pulled from the cells every 3 days to remove the slime blanket that forms. This slime contains 70 pct Sb, 11 pct Pb, less than 5 pct As, less than 1 pct Sn, and less than 0.1 pct Ag. It is assumed that the slime can be sold to recover these metal values.

When 60 pct of the anode is consumed, it is pulled from the refining cell and returned to the anode casting section to be remelted and recast as an anode. Current density in the cell is about 170 A/m^2 at a cell voltage of 0.3 V. Average current efficiency in laboratory studies was about 98 pct with an average power consumption of 0.09 kW·h/kg Pb recovered. The cathode lead assays 99.99 pct Pb.

Electrowinning

Loaded electrolyte from the leaching section is fed to a head tank from which it flows to the electrowinning cells. These cells are identical to the electrorefining cells with the exception of the anode, which is titanium coated with insoluble lead dioxide. The anode was developed and patented (4) at the Bureau's Rolla Research Center. Cell voltage is maintained at 2.5 V with a current density of 170 A/m^2.

During electrowinning about one-third of the lead in solution is reduced. The cell reaction is assumed to be

$$2PbSiF_6 + 2H_2O \rightarrow 2Pb + 2H_2SiF_6 + O_2.$$

Normally the reaction would be

$$2PbSiF_6 + 2H_2O \rightarrow Pb + PbO_2 + 2H_2SiF_6.$$

The presence of phosphate in the electrolyte (found normally in byproduct fluosilicic acid) seems to favor the first reaction. Over 99 pct of the lead reacted is recovered as metallic lead at the cathode. The small quantity of lead recovered as PbO_2 at the anode is recycled to the carbonate leach. Current efficiencies are 95 pct or better with overall power consumption of 0.8 kW·h/kg Pb recovered.

The lead remaining (about 70 g/L) in the electrolyte forms a recirculating load in the acid leach-electrowinning circuit. Reducing a higher percentage of lead would reduce current efficiencies.

Spent electrolyte flows from the electrowinning cells to a sump from which it is returned to the leaching section. In the test work to date impurity buildup has not been a problem. Some electrolyte will be lost to the acid leach residue and other causes such as drag out. Makeup fluosilicic acid should be byproduct acid from the manufacture of phosphate fertilizer to take advantage of its natural phosphate content.

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AMMONIA RECOVERY SECTION

Leachate from the ammoniacal treatment contains ammonium carbonate, ammonium sulfate, and some ammonium hydroxide. This stream is mixed with lime and fed to a steam stripping tower. The lime ties up the sulfate ions, freeing the ammonia, which is pulled off the tower as a vapor. The ammonium carbonate decomposes and leaves the tower as ammonia and carbon dioxide. Gypsum formed in the stripping tower is separated from the remaining solution by filtration.

Filtrate from the gypsum filter is used to absorb the ammonia and carbon dioxide gases from the stripping. Makeup ammonia and carbon dioxide are also absorbed in this step. Sulfur dioxide is then bubbled through this solution to produce ammonium bisulfite for the recycle leach solution.

ECONOMICS

The intent of an economic evaluation is to present a capital and operating cost estimate of a commercial-size plant. Such estimates may be used as an aid for studies and decisions on the course of future research.

In the preparation of any economic evaluation, it is necessary to make many assumptions. In general, the assumptions that are made are expected either to apply to the majority of the potential plants or to have only a small effect on the process capital and operating costs. An example of such an assumption in this report is that most of the plant operates three shifts per day, 7 d/wk.

However, if an assumption is necessary that may not apply to a majority of plants and that may have a major effect on capital or operating costs, then the assumption is generally excluded from the evaluation. An example of such an exclusion is that land cost has not been included in the capital or operating cost estimates. When an assumption has been made or when it has been deliberately excluded, this fact is documented in the report.

Because of the large number of assumptions necessarily present in its economic evaluations, the Bureau strives to present its evaluations in a format sufficiently detailed and flexible to allow a user to make any adjustments that would fit the evaluation to a particular situation.

CAPITAL COSTS

The capital cost estimate is of the general type called a study estimate by Weaver and Bauman (5). This type of estimate, prepared from a flowsheet and a minimum of equipment data, can be expected to be within 30 pct of the actual cost for the plant described. The estimated fixed capital cost on a fourth quarter 1984 basis (Marshall and Swift (M and S) index of 785.2) for a plant processing 10,000 batteries per day is about $14 million, as shown in table 1. Based on an average production of 164,000 lb/d Pb, this translates to a capital investment of $0.26 per annual pound.

Equipment costs for the process are based on cost-capacity data and manufacturers' cost quotations. Exceptions are the electrorefining and electrowinning cells. These have been hand designed and costed based on commercial electrorefining and electrowinning cell designs. Equipment costs for each section are shown in tables A-6 through A-10. Cost data are brought up to date by the use of inflation indexes. In developing the plant capital costs, corrosion-resistant materials of construction were used where appropriate. For example, the leach tanks are steel, lined with polyester, and acid-resistant brick.

Factors for piping, etc., except for the foundation and electrical factors, are assigned to each section, using as a basis the effect fluids, solids, or a combination of fluids and solids may have on the process equipment. The foundation cost is estimated for each piece of equipment individually, and a factor for the entire section is calculated from the totals. The electrical factor is based on motor horsepower requirements for each section. A factor of 10 pct, referred to

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TABLE 1. - Estimated capital cost[1]

Fixed capital:	
Feed preparation section	$1,767,800
Anode casting section	1,567,800
Leaching section	1,776,300
Electrolysis section	4,650,700
Ammonia recovery section	453,000
Steamplant	94,900
Subtotal	10,310,500
Plant facilities, 10 pct of above subtotal	1,031,100
Plant utilities, 12 pct of above subtotal	1,237,300
Basic plant cost	12,578,900
Escalation costs during construction	483,300
Total plant cost	13,062,200
Land cost	0
Subtotal	13,062,200
Interest during construction period	1,007,100
Fixed capital cost	14,069,300
Working capital:	
Raw material and supplies	300,000
Product and in-process inventory	673,300
Accounts receivable	673,300
Available cash	493,700
Working capital cost	2,140,300
Capitalized startup costs	140,700
Subtotal	2,281,000
Total capital cost	16,350,300

[1]Basis: M and S equipment cost index of 785.2.

as miscellaneous, is added to each section to cover minor equipment and construction costs that are not shown with the equipment listed.

For each section, the field indirect cost, which covers field supervision, inspection, temporary construction, equipment rental, and payroll overhead, is estimated at 10 pct of the direct cost. Engineering cost is estimated at 5 pct, and administration and overhead cost is estimated at 5 pct of the construction cost. A contingency allowance of 10 pct and a contractor's fee of 5 pct are included in the section cost.

The costs of plant facilities and plant utilities are estimated as 10 and 12 pct, respectively, of the total process section costs and include the same field indirect costs, engineering, administration and overhead, contingency allowance, and contractor's fee as are included in the section costs. Included under plant facilities are the costs of material and labor for auxiliary buildings such as offices, shops, laboratories, and cafeterias, and the cost of nonprocess equipment such as office furniture, together with safety, shop, and laboratory equipment. Also included are labor and material costs for site preparation such as site clearing, grading, drainage, roads, and fences. The cost of water, power, and steam distribution systems is included under plant utilities.

Inflation during construction can be a major economic factor; therefore, an estimation of the effects of inflation is included as escalation costs during construction. An expenditure schedule based on the basic plant cost is adjusted on a monthly basis to obtain the escalation cost. Over a construction period of 18 months the inflation rate is assumed to be constant at 5 pct annually.

The cost for interest on the capital borrowed for construction is included as interest during construction. A simple

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annual interest rate of 10 pct has been assumed. The same expenditure schedule used to calculate escalation costs during construction is used to adjust the interest rate over the construction period. Land investment is not included in this estimate. Cost for the plant owner's supervision is not included in the capital cost of the processed plant.

Working capital is defined as the funds in addition to fixed capital, land investment, and startup costs that must be provided to operate the plant. Working capital, also shown in table 1, is estimated from the following items: (1) Raw material and supplies inventory (cost of raw material and operating supplies for 30 days), (2) product and in-process inventory (total operating cost for 30 days), (3) accounts receivable (total operating cost for 30 days), and (4) available cash (direct expenses for 30 days).

Capitalized startup costs are estimated as 1 pct of the fixed capital, which is shown in table 1.

OPERATING COSTS

The estimated operating costs are based on 330 d/yr operation over the life of the plant. This allows 35 d/yr downtime for inspection, maintenance, and unscheduled interruptions. The operating costs are divided into direct, indirect, and fixed costs.

Direct costs include raw materials, utilities, direct labor, plant maintenance, payroll overhead, and operating supplies. The raw material costs do not include transportation costs. Electricity, water, and natural gas are purchased utilities. Raw material and utility requirements per pound of lead are shown in table A-1.

Direct labor costs are estimated on the basis of assigning 4.2 employees to each position that operates 24 h/d, 7 d/wk, and 1.4 employees to each position that operates 8 h/d, 7 d/wk. Sectional labor requirements are shown in table A-2. The cost of labor supervision is estimated as 15 pct of the labor cost.

Plant maintenance is separately estimated for each piece of equipment and for the buildings, electrical system, piping, plant utility distribution systems, and plant facilities.

Payroll overhead, estimated as 35 pct of direct labor and maintenance labor, includes vacation, sick leave, Social Security, and fringe benefits. The cost of operating supplies is estimated as 20 pct of the cost of plant maintenance.

Indirect costs are estimated as 40 pct of the direct labor and maintenance costs. The indirect costs include the expenses of control laboratories, accounting, plant protection and safety, plant administration, marketing, and company overhead. Research and overall company administrative costs outside the plant are not included.

Fixed costs include the cost of taxes (excluding income taxes), insurance, and depreciation. The annual costs of both taxes and insurance are each estimated as 1 pct of the plant construction cost. Depreciation is based on a straight-line, 10-yr period.

The estimated annual operating cost for the proposed plant is about $8.2 million, as shown in table 2. Based on a production of 164,380 lb/d Pb, 330 d/yr, this corresponds to a cost of $0.15/lb Pb.

PRODUCTS

Products from the proposed process include 164,380 lb/d Pb and 5,832 lb/d Sb slimes. In addition, about 60,000 lb/d plastic and rubber will be recovered. Between 56,400 and 83,300 lb/d byproduct gypsum will be recovered depending on the strength of the waste battery acid. At an average of 14 pct H_2SO_4 the quantity of gypsum will be 73,230 lb. About 22,000 lb/d residue from the acid leach step is also recovered.

The lead, antimony slimes, and plastic products should be marketable. Both the byproduct gypsum and the leach residue will be relatively stable waste products, which can be disposed of in a landfill. The rubber recovered will probably be considered a hazardous waste and will have to be handled as such. Product values or disposal costs are shown in table 3. The assumed disposal cost for

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TABLE 2. - Estimated annual operating cost

	Annual cost	Cost per pound lead
Direct cost:		
Raw materials:		
Whole batteries at $50/st	$2,348,800	$0.043
Fluosilicic acid at $92/st	373,400	.007
Ammonia at $210/st	29,100	.001
Carbon dioxide at $90/st	283,000	.005
Sulfur dioxide at $210/st	264,700	.005
Filter aid at $150/st	82,400	.002
Lime at $30.75/st	120,800	.002
Clue at $0.85/lb	1,700	[1].000
Calcium lignin sulfonate at $0.25/lb	11,800	[1].000
Chemicals for steamplant water treatment	700	[1].000
Total	3,516,400	.065
Utilities:		
Electric power at $0.047/kW·h	512,100	.009
Process water at $0.25/Mgal	4,900	[1].000
Natural gas at $4.50/MMBtu	201,600	.004
Total	718,600	.013
Direct labor:		
Labor at $9/h	542,900	.010
Supervision, 15 pct of labor	81,400	.002
Total	624,300	.012
Plant maintenance:		
Labor	303,600	.006
Supervision, 20 pct of maintenance labor	60,700	.001
Materials	303,500	.006
Total	667,800	.013
Payroll overhead, 35 pct of above payroll	346,000	.006
Operating supplies, 20 pct of plant maintenance	133,600	.002
Total direct cost	6,006,700	.114
Indirect cost, 40 pct of direct labor and maintenance	516,800	.010
Fixed cost:		
Taxes, 1 pct of total plant cost	130,600	.002
Insurance, 1 pct of total plant cost	130,600	.002
Depreciation, 10-yr life	1,406,900	.026
Total operating cost	8,191,600	.151

[1]Numbers have been rounded down to $0.000.

gypsum and leach residues is a compromise between typical costs for urban and rural disposal. The values used for the lead and plastic products are based on published prices for competitive materials (i.e., primary lead and plastic resins).

PROFITABILITY

Based on the estimated operating cost and the projected product values, the interest rate of return on investment after taxes is 11 pct, using the interest rate of return method for calculations. Normally, consideration of a new project would require a 15-pct rate of return on investment after taxes as a minimum. This preceding calculation is based on the March 1985 lead price of $0.17/lb. Secondary lead is listed at $0.21/lb. Based on this value, the interest rate of return on investment after taxes is 20 pct. Since the price of lead is not stable at the moment, figure 2 is presented to show how the estimated interest rate

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TABLE 3. - Product values

	Daily production	Estimated unit value	Annual returns (debits) on sales	Value per pound lead product
Products:				
Lead metal.....	164,380 lb	$0.17/lb	$9,222,000	$0.17
Antimony slimes.....	5,832 lb	.58/lb	1,116,000	.021
Plastic[1].....	54,000 lb	.05/lb	891,000	.016
Subtotal.....	NAp	NAp	11,229,000	.207
Waste products:				
Gypsum.....	36.6 st	-10.00/st	-121,000	-.002
Leach residues.....	11.2 st	-10.00/st	-37,000	-.001
Rubber[1].....	3.0 st	-100.00/st	-99,000	-.002
Subtotal.....	NAp	NAp	-257,000	-.005
Total.....	NAp	NAp	10,972,000	.202

NAp Not applicable.

[1]Total daily production of plastic and rubber is 60,000 lb. To compute product values, the plastic product is estimated to be 90 pct of the total and the waste rubber is estimated to be 10 pct.

of return on investment after taxes will change with changing lead prices. Included in the rate of return calculations are the revenues (debits) for the potential byproducts, as shown in table 3.

ALTERNATE LEACH PROCESS

To date, the main emphasis of the Bureau's research has been to develop a process to efficiently extract lead from battery scrap as pure metal. One proposed alternative would be to change the leach procedure. Only the lead sulfate would be leached, leaving the lead dioxide in the leach residue. The leach residue would then be sold to a lead smelter for its lead content.

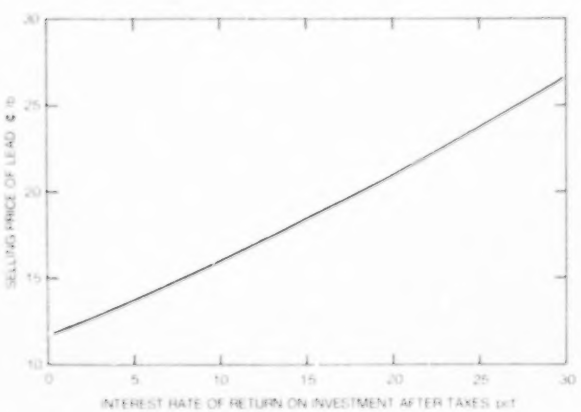

FIGURE 2. - Selling price of lead versus interest rate of return on investment after taxes.

The advantage of this flowsheet is that the leach-electrowinning circuit would be simplified. Less ammonium carbonate leach solution is required, and the need for ammonium bisulfite is eliminated. Less lead will be electrowon; therefore, the electrowinning circuit is smaller. Ammonia recovery equipment is also smaller as less ammonia has to be circulated. Since electrorefining requires less energy than electrowinning, electrical energy requirements are reduced from 0.20 kW·h/lb to 0.178 kW·h/lb Pb.

The Bureau has not investigated the alternate process and has no actual data to verify that these advantages will be realized. For this reason, a detailed cost evaluation of this process is not presented. It is possible, however, to project costs for a hypothetical process assuming that only the outlined changes occur without any additional complications. All costs presented are intended to indicate what the potential of this process may be, and any comparison to the original process has to be qualified owing to the lack of supportive data available.

Fixed capital costs for the alternate leach process are reduced about $1.3 million, or 9 pct. Operating costs per unit of recovered lead are increased about 1.3

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pct, or $0.002/lb Pb recovered. Byproduct credits, however, for this process are much higher (table B-3). This results in an estimated interest rate of return on investment after taxes of 15.4 pct with a lead price of $0.17/lb. At $0.21/lb Pb, the interest rate of return on investment will be 25 pct. Thus, the alternate leach process appears to have more economic potential, if a market for the leach residue is available. Capital and operating costs for this process are presented in tables B-1 and B-2.

CONCLUSIONS

1. The fixed capital cost for a plant sized to process 10,000 scrap batteries per day is estimated to be about $14 million based on fourth quarter 1984 equipment costs.

2. The estimated operating cost for this plant is $0.15/lb Pb recovered.

3. At a selling price of $0.17/lb, the interest rate of return on investment after taxes is calculated to be 11 pct.

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APPENDIX A.--UTILITY REQUIREMENTS, DIRECT LABOR REQUIREMENTS, MAJOR ITEMS OF EQUIPMENT, DAILY THERMAL AND UTILITY REQUIREMENTS, AND EQUIPMENT COST SUMMARIES

Raw material and utility requirements per pound of lead are shown in table A-1. The labor requirements and the major items of equipment for each section are shown in tables A-2 and A-3, respectively. Daily thermal and utility requirements for each section are shown in tables A-4 and A-5, respectively. The equipment cost summaries for each section in the process are contained in tables A-6 to A-10.

TABLE A-1. - Raw material and utility requirements

	Quantity per pound lead
Raw materials, lb:	
Whole batteries	1.732
Fluosilicic acid	.150
Ammonia	.005
Carbon dioxide	.116
Sulfur dioxide	.046
Filter aid	.020
Lime	.145
Glue	.000
Calcium lignin sulfonate	.001
Utilities:	
Electric power, kW-h	.201
Process water, gal	.365
Natural gas, thm	.083

TABLE A-2. - Direct labor requirements, operators per shift

Section	Shifts per week		
	[1]21	[2]14	[3]5
Feed preparation	0.0	2	0
Anode casting	0	5	0
Electrolysis	2.5	0	4
Ammonia recovery	.5	0	0
Steamplant	1	0	0
Total	4.0	7	4

[1] 3 shifts per day, 7 d/wk.
[2] 2 shifts per day, 7 d/wk.
[3] 1 shift per day, 5 d/wk.

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TABLE A-3. - Major items of equipment

Section and equipment	Quantity	Size
Feed preparation: Reclamation system	1	1,800 batteries per hour.
Anode casting:		
Melting furnace	1	135 ft^3.
Anode casting wheel	1	15 anodes per hour.
Leaching:		
Carbonate leach tank	1	1,200 gal.
Carbonate leach filter	1	250 ft^2.
Acid leach tank	1	6,000 gal.
Acid leach filters	2	400 ft^2.
Electrolysis:		
Electrorefining cells	30	175 lb/h.
Melting furnace	1	550 ft^3.
Casting machine	1	100 ft long.
Electrowinning cells	17	300 lb/h.
Rectifier	1	1,600 kW.
Ammonia recovery section:		
Bubble tank	1	1,800 gal.
2-effect evaporator	1	144 ft^2 per effect.
Rotary-vacuum drum filter	1	50 ft^2.

TABLE A-4. - Daily thermal requirements

Section and item	Steam, MMBtu	Natural gas, MMBtu
Anode casting: Melting furnace	0.00	11.28
Leaching:		
Carbonate leach tank	7.00	.00
Acid leach tank	8.60	.00
Subtotal	15.60	.00
Electrolysis: Melting furnace	.00	9.53
Ammonia recovery: Evaporator	33.20	.00
General plant	.00	17.00
Total process requirements	48.80	37.81
Steamplant	-48.80	97.92
Grand total	.00	135.73

TABLE A-5. - Daily utility requirements

Section and major process water consumer	Electric[1] power, kW·h	Process water, Mgal
Feed preparation: Reclamation system	NAp	9.5
Section total	1,380	9.5
Anode casting	247	.0
Leaching:		
Carbonate leach filter	NAp	4.7
Acid leach filters	NAp	1.7
Section total	1,801	6.4
Electrolysis	22,496	.0
Ammonia recovery: Bubble tank	NAp	37.8
Section total	369	37.8
Steamplant	115	5.8
General plant	6,610	.0
Plant total	33,018	59.5

NAp Not applicable.
[1] Individual electric power consumers not shown; only major process water consumer shown.

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TABLE A-6. - Equipment cost summary, feed preparation section

Item	Equipment[1]	Labor	Total
Belt conveyor	$17,800	$5,100	$22,900
Belt conveyor	20,200	5,800	26,000
Lime storage	11,400	3,000	14,400
Screw feeder	2,300	500	2,800
Slurry tank	1,500	700	2,200
Pumps	1,900	1,100	3,000
Storage tanks	15,900	4,100	20,000
Pump	1,700	1,000	2,700
Sand filter	41,300	1,500	42,800
Holding tank	21,100	8,900	30,000
Total	135,100	31,700	166,800
Reclamation system[2]			910,600
Front-end loader			39,700
Total equipment cost × factor indicated:			
Foundations, × 0.511			69,100
Structures, × 0.070			9,500
Instrumentation, × 0.050			6,800
Electrical, × 0.142			19,100
Piping, × 0.200			27,000
Painting, × 0.020			2,700
Miscellaneous, × 0.100			13,500
Total			147,700
Total direct cost			1,264,800
Field indirect, 10 pct of total direct cost			126,500
Total construction cost			1,391,300
Engineering, 5 pct of total construction cost			69,600
Administration and overhead, 5 pct of total construction cost			69,600
Subtotal			1,530,500
Contingency, 10 pct of above subtotal			153,100
Subtotal			1,683,600
Contractor's fee, 5 pct of above subtotal			84,200
Section cost			1,767,800

[1]Basis: M and S equipment cost index of 785.2.

[2]Installed cost.

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TABLE A-7. - Equipment cost summary, anode casting section

Item	Equipment[1]	Labor	Total
Surge bin	$5,600	$1,500	$7,100
Apron feeder	8,200	1,600	9,800
Melting furnace	244,900	9,500	254,400
Bag dust collector	28,400	500	28,900
Anode casting wheel	208,400	19,000	227,400
Total	495,500	32,100	527,600
Slag mold[2]			1,300
Straddle carrier[2]			264,800
Forklift trucks			30,500
Total equipment cost × factor indicated:			
Foundations, × 0.083			41,300
Buildings, × 0.079			39,000
Structures, × 0.050			24,800
Instrumentation, × 0.100			49,600
Electrical, × 0.018			9,100
Piping, × 0.150			74,300
Painting, × 0.020			9,900
Miscellaneous, × 0.100			49,600
Total			297,600
Total direct cost			1,121,800
Field indirect, 10 pct of total direct cost			112,200
Total construction cost			1,234,000
Engineering, 5 pct of total construction cost			61,700
Administration and overhead, 5 pct of total construction cost			61,700
Subtotal			1,357,400
Contingency, 10 pct of above subtotal			135,700
Subtotal			1,493,100
Contractor's fee, 5 pct of above subtotal			74,700
Section cost			1,567,800

[1]Basis: M and S equipment cost index of 785.2.

[2]Installed cost.

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TABLE A-8. - Equipment cost summary, leaching section

Item	Equipment[1]	Labor	Total
Sludge bin	$6,000	$1,600	$7,600
Screw feeder	2,300	500	2,800
Carbonate leach tank	7,000	2,100	9,100
Carbonate leach filter	89,800	12,000	101,800
Pump	1,500	700	2,200
Belt conveyor	5,800	1,500	7,300
Bucket elevator	6,000	2,200	8,200
Acid leach tank	50,300	4,800	55,100
Acid holding tank	28,700	4,100	32,800
Pump	5,300	700	6,000
Vibrating screen	8,700	1,400	10,100
Hopper	300	100	400
Acid leach filters	367,300	24,500	391,800
Belt conveyor	19,100	4,800	23,900
Pump	4,900	1,000	5,900
Total	603,000	62,000	665,000
Total equipment cost × factor indicated:			
Foundations, × 0.114			68,600
Buildings, × 0.237			164,700
Structures, × 0.090			54,300
Instrumentation, × 0.100			60,300
Electrical, × 0.058			34,900
Piping, × 0.250			150,800
Painting, × 0.020			12,100
Miscellaneous, × 0.100			60,300
Total			606,000
Total direct cost			1,271,000
Field indirect, 10 pct of total direct cost			127,100
Total construction cost			1,398,100
Engineering, 5 pct of total construction cost			69,900
Administration and overhead, 5 pct of total construction cost			69,900
Subtotal			1,537,900
Contingency, 10 pct of above subtotal			153,800
Subtotal			1,691,700
Contractor's fee, 5 pct of above subtotal			84,600
Section cost			1,776,300

[1]Basis: M and S equipment cost index of 785.2.

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TABLE A-9. - Equipment cost summary, electrolysis section

Item	Equipment[1]	Labor	Total
Bridge crane	$88,000	$4,600	$92,600
Electrolyte head tank	19,300	4,000	23,300
Electrorefining cells	180,100	39,900	220,000
Melting furnace	123,000	17,100	140,100
Casting machine	179,400	28,500	207,900
Sumps	7,900	6,200	14,100
Pumps	9,200	2,600	11,800
Electrowinning cells	245,600	22,600	268,200
Sumps	9,000	8,200	17,200
Pumps	15,300	3,700	19,000
Recycle tank	27,800	4,100	31,900
Pump	3,600	1,200	4,800
Starter sheet preparation	54,600	19,000	73,600
Total	962,800	161,700	1,124,500
Rectifier[2]			353,500
Total equipment cost × factor indicated:			
Foundations, × 0.130			125,600
Buildings, × 0.886			852,900
Structures, × 0.070			67,400
Insulation, × 0.030			28,900
Instrumentation, × 0.100			96,300
Electrical, × 0.235			226,000
Piping, × 0.350			337,000
Painting, × 0.020			19,300
Miscellaneous, × 0.100			96,300
Total			1,849,700
Total direct cost			3,327,700
Field indirect, 10 pct of total direct cost			332,800
Total construction cost			3,660,500
Engineering, 5 pct of total construction cost			183,000
Administration and overhead, 5 pct of total construction cost			183,000
Subtotal			4,026,500
Contingency, 10 pct of above subtotal			402,700
Subtotal			4,429,200
Contractor's fee, 5 pct of above subtotal			221,500
Section cost			4,650,700

[1]Basis: M and S equipment cost index of 785.2.
[2]Installed cost.

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TABLE A-10. - Equipment cost summary, ammonia recovery section

Item	Equipment[1]	Labor	Total
Bubble tank	$5,400	$2,500	$7,900
Vent scrubber	27,200	3,600	30,800
Pump	2,400	400	2,800
Mixing tank	1,900	700	2,600
Storage bin	2,000	600	2,600
Screw feeder	2,300	500	2,800
Pump	1,300	800	2,100
2-effect evaporator	27,300	15,000	42,300
Pumps	9,900	1,500	11,400
Rotary-vacuum drum filter	51,200	6,800	58,000
Storage tank	200	600	800
Pump	1,300	700	2,000
Belt conveyor	15,400	4,800	20,200
Total	147,800	38,500	186,300
Total equipment cost × factor indicated:			
Foundations, × 0.080			11,800
Structures, × 0.070			10,300
Instrumentation, × 0.100			14,800
Electrical, × 0.163			24,100
Piping, × 0.400			59,100
Painting, × 0.020			3,000
Miscellaneous, × 0.100			14,800
Total			137,900
Total direct cost			324,200
Field indirect, 10 pct of total direct cost			32,400
Total construction cost			356,600
Engineering, 5 pct of total construction cost			17,800
Administration and overhead, 5 pct of total construction cost			17,800
Subtotal			392,200
Contingency, 10 pct of above subtotal			39,200
Subtotal			431,400
Contractor's fee, 5 pct of above subtotal			21,600
Section cost			453,000

[1]Basis: M and S equipment cost index of 785.2.

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APPENDIX B.--ALTERNATE LEACH PROCESS

The estimated capital cost and the annual operating cost, for the alternate leach process, are shown in tables B-1 and B-2, respectively. Table B-3 shows product values.

TABLE B-1. - Estimated capital cost,[1] alternate leach process

Fixed capital:	
Feed preparation section	$1,767,800
Anode casting section	1,567,800
Leaching section	1,252,400
Electrolysis section	4,176,700
Ammonia recovery section	511,100
Steamplant	94,900
Subtotal	9,370,700
Plant facilities, 10 pct of above subtotal	937,100
Plant utilities, 12 pct of above subtotal	1,124,500
Basic plant cost	11,432,300
Escalation costs during construction	439,200
Total plant cost	11,871,500
Land cost	0
Subtotal	11,871,500
Interest during construction period	915,300
Fixed capital cost	12,786,800
Working capital:	
Raw material and supplies	258,700
Product and in-process inventory	602,200
Accounts receivable	602,200
Available cash	437,100
Working capital cost	1,900,200
Capitalized startup costs	127,900
Subtotal	2,028,100
Total capital cost	14,814,900

[1]Basis: M and S equipment cost index of 785.2.

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TABLE B-2. - Estimated annual operating cost, alternate leach process

	Annual cost	Cost per pound lead
Direct cost:		
Raw materials:		
Whole batteries at $50/st	$2,348,800	$0.049
Fluosilicic acid at $92/st	373,400	.008
Ammonia at $210/st	10,000	[1].000
Carbon dioxide at $90/st	110,400	.002
Filter aid at $150/st	82,400	.002
Lime at $30.75/st	87,000	.002
Glue at $0.85/lb	1,700	[1].000
Calcium lignin sulfonate at $0.25/lb	11,800	.001
Chemicals for steamplant water treatment	700	[1].000
Total	3,026,200	.064
Utilities:		
Electric power at $0.047/kW·h	399,900	.008
Process water at $0.25/Mgal	3,900	[1].000
Natural gas at $4.50/MMBtu	199,900	.004
Total	603,700	.012
Direct labor:		
Labor at $9/h	542,900	.011
Supervision, 15 pct of labor	81,400	.002
Total	624,300	.013
Plant maintenance:		
Labor	276,100	.006
Supervision, 20 pct of maintenance labor	55,200	.001
Materials	276,200	.006
Total	607,500	.013
Payroll overhead, 35 pct of above payroll	334,500	.007
Operating supplies, 20 pct of plant maintenance	121,500	.003
Total direct cost	5,317,700	.112
Indirect cost, 40 pct of direct labor and maintenance	492,700	.010
Fixed cost:		
Taxes, 1 pct of total plant cost	118,700	.002
Insurance, 1 pct of total plant cost	118,700	.002
Depreciation, 10-yr life	1,278,700	.027
Total operating cost	7,326,500	.153

[1]Numbers have been rounded down to $0.000.

TABLE B-3. Product values, alternate leach process

	Daily production	Estimated unit value	Annual returns (debits) on sales	Value per pound lead product
Products:				
Lead metal	144,890 lb	$0.17/lb	$8,128,000	$0.17
Lead dioxide residue	39,840 lb	.07/lb	960,000	.02
Antimony slimes	5,832 lb	.58/lb	1,116,000	.023
Plastic[1]	54,000 lb	.05/lb	891,000	.019
Subtotal	NAp	NAp	11,095,000	.232
Waste products:				
Gypsum	28.6 st	-10.00/st	-94,000	-.002
Rubber[1]	3.0 st	-100.00/st	-99,000	-.002
Subtotal	NAp	NAp	-183,000	-.004
Total	NAp	NAp	10,912,000	.228

NAp Not applicable.

[1]Total daily production of plastic and rubber is 60,000 lb. To compute product values, the plastic product is estimated to be 90 pct of this total and the waste rubber is estimated to be 10 pct.

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